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Mitigation measures in the 'smart inventory': Practical abatement potential in Scottish agriculture

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Executive summary

The UK's inventory of greenhouse gas emissions measures progress towards reduction targets. The methodology for agriculture has recently changed to better reflect the relationship between agricultural management and GHG emissions.

The new methodology is called the 'smart inventory'. It estimates the GHG effects of a wider range of technologies and management options than was included in previously (inclusion of technology details mostly depend on the existence of robust scientific evidence about the emission effect). Nevertheless, for some of these technologies data on the current uptake is not yet available, and there are further technologies where the scientific evidence is not robust enough to make conclusive recommendations or include in the smart inventory.

This report summarises the extent certain agricultural practice changes in Scotland are (or could be) recognised in the smart inventory. The purpose of this assessment is to provide information to policy makers on what changes in Scottish agricultural practices are reflected in the UK GHG inventory, and, additionally, what further steps could be taken to reflect Scottish agricultural practices more accurately.

Key findings

- The smart inventory is only reflecting the mitigation activities for which we currently have robust data and analysis
- Annual Scotland-specific data are used in many activities (e.g. crop areas, fertilisation rates livestock numbers, milk yield, slaughter weight), but more specific activity data either are either not updated annually or not systematically collected for Scotland.
- Inventory development is a continuous process and future data collection should be planned with the Inventory team in order to maximise the use of the data in the inventory.
- Four broad groups of measures were identified:
    - a Measures in the inventory that would benefit from specific Scottish activity data.
    - b Measures which are planned to be included in the inventory, and which would benefit from specific Scottish activity data.
    - c Measures where the effects could be mostly captured with overall efficiency metrics; for these measures no major additional actions are suggested;
    - d Measures which lack readily available robust evidence on GHG effects.

- There are four main data categories that would enhance data collection initially:
  a Nitrogen fertilisation of minor crops and novel legumes,
  b Area and fertilisation information on intercropping,
  c Ruminant diets,
  d Manure management and storage information.

Table 1 is a summary of what changes to the inventory might help each measure to be represented more accurately.

Table 1 Suggestions for each measure

Measure	**Mechanism briefly**	**Summary suggestions for inventory changes required to represent mitigation more accurately**
Avoiding nitrogen excess	Lower nitrogen input, potentially a non-linear response to reducing nitrogen	Representation of the measure would require establishing field-level nitrogen optima and comparing it with field-level nitrogen application data; Introducing full non-linear EF_1 could improve estimates; Trends of nitrogen use (and N_2O emissions) by crop and fertiliser type are estimated; that together with crop production data can inform on efficiency of nitrogen use[1]
Biological nitrogen fixation in rotations	Lower nitrogen input, carry-over effect (lower nitrogen on subsequent crop), less fuel emissions from nitrogen spreading	Some improvements could potentially be achieved by using more granular nitrogen application data (particularly regarding intercropping and carry-over effect)
Biological nitrogen fixation in grassland	Lower nitrogen input, leaching, increases livestock's nitrogen excretion due to higher nitrogen content	Bigger sample of Scotland specific clover-grass area and fertilisation data at the farm scale could improve estimates for Scotland
Nitrification inhibitors and natural nitrification inhibitors	Reduces EF_1	Scotland specific data on the use of nitrification inhibitors if uptake starts increasing could help accuracy

[1] Regarding efficiency calculations it is worth noting that production data (e.g. amount of wheat produced) and production GHG efficiency are not published in the inventory, though efficiency values can be derived if the inventory results are used in combination with other data sources

Measure	Mechanism briefly	Summary suggestions for inventory changes required to represent mitigation more accurately
Plant growth promoters	Increasing nitrogen uptake and growth (yield) by plants, potentially reducing nitrogen losses from the soil, but also increasing nitrogen in crop residue	nitrogen use efficiency in Scotland can be already established from inventory data and yield data (indirectly includes effect); evidence on other effects (e.g. on nitrogen leaching) needs to be established
Removing stock from wet ground	Reduces soil compaction and therefore high nitrous oxide emissions (EF_1), the emissions from excretion changes for the stand off period too	Collation of evidence (as of how soil wetness affects emissions) would be needed as well as baseline data on the number of wet days and collection of activity information
High starch diet for ruminants	Reduces enteric CH_4 emissions (*via* increasing digestibility) and nitrogen excretion	Statistical (including Scottish) data collection on rations could improve the representation of the measure
Higher sugar content grasses	Reduce nitrogen excreted, can increase milk yields and animal growth rates	Representation of the measure would require establishing emission parameters and collection of activity data (sales data available, but not the extent of high sugar grasses in the fields or their nutritional composition, which is important for the mitigation effect and depend on the nitrogen fertilisation rate of the grassland)
Better livestock health planning	Increases productivity of the herd (reduces emission intensity), but unlikely to lead to reduced absolute emissions	Indirect emission intensity effect can be derived from the inventory, though that could be improved with statistical data on feeding
Livestock breeding for lower emission intensity	Animal and herd level efficiency improvements resulting in lower feed intake and/or higher yield	Indirect emission intensity effect can be derived from the inventory, though that could be improved with statistical data on feeding
Ruminant genetic selection for reduced methanogenesis	Reduced enteric methane with no change in the diet and no decrease in the yield	Representation of the measure would require the update of enteric methane emission parameter

Measure	**Mechanism briefly**	**Summary suggestions for inventory changes required to represent mitigation more accurately**
Covering slurry stores	Covering slurry tanks reduces gaseous losses of ammonia with some reduction of methane, acting as a physical barrier for diffusion into the atmosphere	Collection of Scotland specific activity data could improve accuracy
Anaerobic digestion of livestock excreta	Reduces methane and nitrous oxide emissions from manure storage, reduce/increase nitrous oxide emissions from land application of digestate, replaces energy	Collection of Scotland specific activity data could improve accuracy
Methane capture and combustion	Converts methane to carbon dioxide reducing the global warming potential	Representation of the measure would require establishing emission parameters and collection of activity data

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Glossary

GHG emissions: Emissions of greenhouse gases to atmosphere, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

GHG Platform Programme: An integrated programme of research funded by Defra and the devolved authorities in the UK designed to improve the UK's reporting of agricultural GHG emissions. http://www.ghgplatform.org.uk/

IPCC: The Intergovernmental Panel on Climate Change, United Nations body for assessing the science related to climate change. https://www.ipcc.ch/

Smart Inventory: the GHG Inventory methodology for agricultural emissions in the UK, implemented in 2018, which contains UK specific, Tier 3 level emission calculations[2]

Tier 1 Methodology: the basic IPCC methodology for assessing GHG emissions, based on default emissions factors provided by IPCC

Tier 2 Methodology: more detailed IPCC methodology for assessing GHG emissions; it generally uses the same methodological approach as Tier 1 but applies emission factors and other parameters which are specific to the country

Tier 3 Methodology: the most detailed IPCC methodology for assessing GHG emissions using higher-order methods (e.g. models and spatial data) to address national circumstances with greater certainty than lower tiers

[2] https://www.theccc.org.uk/wp-content/uploads/2018/08/PR18-Chapter-6-Annex-The-Smart-Agriculture-Inventory.pdf

Abbreviations

BSFP	British Survey of Fertiliser Practice (https://www.gov.uk/government/collections/fertiliser-usage)
CH_4	Methane
CO_2	Carbon dioxide
DA	Devolved Administration
EF_1	Emission factor representing the proportion of nitrogen applied to soils being emitted as nitrous oxide
FAS	Farm Accounts Survey
FracLeach	Fraction of nitrogen inputs that is lost through leaching and runoff
GHG	Greenhouse gas
JAC	June Agricultural Census
N	Nitrogen
N_2O	Nitrous oxide

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Mitigation Measures in the Smart Inventory

Background

The Scottish Government is committed to statutory targets for the reduction of GHG emissions across all sectors of the economy as a consequence of the Climate Change (Scotland) Act 2009. The plans on achieving these targets is described periodically in the Reports on policies and proposals (Scottish Government 2018). Progress is assessed through monitoring both farmers' activities (as far as current statistics allow) and GHG emission trends as reported in the UK's inventory.

A large programme of research (GHG Platform Programme) has recently been undertaken to improve GHG inventory reporting, and better reflect the relationship between agricultural management and GHG emissions in what are described as smart approaches to inventory reporting (Committee on Climate Change 2018). The first iteration of the smart inventory was published in April 2018, and reports on GHG emissions across the UK between 1990 and 2016 (Brown *et al.* 2018). The new inventory offers additional opportunities for reporting GHG mitigation (i.e. as a consequence of activities and technologies which reduce emissions), for example by using different fertiliser types or livestock diets (Committee on Climate Change 2018).

There are still some agricultural practices which are not reflected in the inventory, or not to an extent which would identify changes in GHG emissions arising from changing practices in Scotland. This project therefore explores the extent agricultural practice changes in Scotland would be recognised in the smart inventory. This project was informed by other relevant research currently being undertaken by UK's Committee on Climate Change and Defra.

Methodology

A list of measures to be assessed was agreed with the project steering group at the start of the project. Evidence on the representation of the measures in the smart inventory was collected from published documents and from discussions with researchers who have been involved in the development of the smart inventory (Steven Anthony, ADAS, Tom Misselbrook, Rothamsted Research, Kairsty Topp, SRUC, Bob Rees, SRUC). The aspects considered were:

- Whether the measure is implicitly or explicitly recognised by the GHG inventory
- A description of the measure journey through the inventory (activity data and emission parameters used) with specific attention to the use of Scotland specific data
- Any interactions with other measures and indication if the mitigation effect is partly included in other sectors in the GHG inventory

Mechanism of the measures and current representation in the inventory

In the agricultural GHG inventory emissions are calculated by estimating the prevalence of 'activities' (e.g. number of livestock, amount of certain type of N used, proportion of various kinds of slurry stores) and assigning parameters to them which estimate the emissions arising from these activities. Depending on the complexity of the calculations, three levels are differentiated in the inventory: Tier 1, Tier 2 and Tier 3. The parameters are either follow the default IPCC parameters (IPCC 2006), or estimated specifically for the UK.

The smart inventory uses mixed methods, combining Tier 3, Tier 2 and Tier 1 approaches, depending on the emission sources and agricultural activities. Enteric CH_4 and CH_4 and N_2O emissions from stored manure from cattle and sheep are represented with Tier 3 calculations, N_2O and CH_4 emissions from manure of other livestock (but deer) are calculated in Tier 2 methods, and Tier 1 methods are used for enteric CH_4 emissions from livestock other than cattle and sheep. N_2O emissions from agricultural soils are estimated via a combined Tier 1 / Tier 2 approach (Brown *et al.* 2018).

The findings of the study are presented in the following sections. More details about the inventory calculation mechanisms for each measure can be found in the Appendix (Table 2, Table 3, Table 4).

Avoiding nitrogen excess

Fertiliser N recommendations are designed to provide crops with the economic optimal N supply (SRUC 2013). Nevertheless, farmers might not always follow these recommendations and some would keep an over-application margin as a protection from yield penalties due to having better than expected growing conditions.

Extensive field experimentation has shown that increasing N fertilisation above the recommended amount results in little or no yield benefit. There is also some emerging evidence to suggest that N_2O emissions show a non-linear response to increasing fertiliser N applications with significantly greater N_2O emissions per unit of N applied at higher N applications (Hoben et al. 2011). The current smart inventory uses a Tier 2 approach to represent a clear relationship between N input and N_2O emissions. Although the emissions model is non-linear, EF_1 has been linearized for typical rates, and therefore EF_1 does not change with small changes in fertiliser rates. Furthermore, though changes in N application rate are represented through a sample of farms, the extent of excess application (or under-application) of individual fields is not established.

Representation of the measure would require establishing the field-level N optima and comparing it with field-level N application data. Introduction of non-linear EF_1 could also improve estimates. Information on N use (and N_2O emissions) by crop and fertiliser type is available from the inventory, and that, together with crop production data can inform policy about efficiency of N use, which can be a proxy for the extent of excessive use of N. However, Scotland specific data on fertiliser use are based on the BSFP, which samples a small numbers of Scottish Farms (1,160 farms from across the UK); Scottish N application activity data could be improved by a larger sample size, particularly for minor crops.

Biological nitrogen fixation in rotations

N fixing crops (legumes) form symbiotic relationships with bacteria in the soil that allows them to fix atmospheric N and use this in place of N provided by synthetic fertilisers. They are able to fix in excess of 300 kg N ha^{-1} y^{-1}, and can supply N to subsequent crops.

The smart inventory considers leguminous crops in separate crop categories with related N fertiliser use data; this granularity allows the representation of the major emission effects of legumes in rotations. For the main legumes, this will be robust. Due to confidentiality, this information may not be available for the novel legumes, although their impact on the national inventory will be minor. Statistics on the area of legumes is sourced from the JAC and legume N fertilisation rates are available from the BSFP. Implicitly the BSFP already accounts for the adjustment made for the effect of the legume in the rotation on the subsequent N fertiliser inputs as this is a survey of existing practice, though the sample size is relatively small (Scottish N application activity data could be improved by a larger sample size, particularly for the novel legumes).

Biological nitrogen fixation in grassland

Legumes have the ability to fix N from the atmosphere. In the legume-grass mixtures, the leguminous crops (e.g. white clover) can provide a substantial part of the grass's N requirements, reducing the need for N fertilisation.

The measure is included in the smart inventory, as grass with clover is represented as a separate crop category. The proportion of swards containing white clover has been estimated from the Countryside Survey[3]. Implicitly the BSFP already accounts for the adjustment made for the effect of clover in grass swards on the subsequent N fertiliser inputs as this is a survey of existing practice. In addition, the FracLeach has been modified to reflect the proportion of clover in the improved grasslands (as clover increases the proportion of N leached from the soil), which is dynamically modelled in UpCycle (Steven Anthony, *pers. comm.*) to reflect N inputs and grazing practices. Furthermore, in the case of the sheep sector, there is a direct link between the proportion of clover in the diet and the N excreted (clover has higher crude protein content than grass and therefore increases N excretion and subsequent N_2O emissions from grazing depositions and manure).

A more accurate estimate of the proportion of swards containing clover may improve the estimation of FracLeach. Including a direct link between the proportion of clover in the grazed diet and the N excreted for cattle would also improve the inventory (currently the proportion of clover in the diet does not directly linked to the proportion of clover in the grass, but needs to be set separately). Although the fertiliser application rates are reasonably robust at the DA level, additional data for each of the farm types would improve the estimation.

Nitrification inhibitors and natural nitrification inhibitors

Nitrification inhibitors depress the activity of nitrifying bacteria, leaving the fertiliser in the soil in ammonium form longer, improving its plant availability (Akiyama *et al.* 2010, Macadam *et al.* 2003, Rodgers 1986). As these compounds are degraded by soil bacteria, the temporary inhibition effect disappears (de Klein *et al.* 2011). Consequently, nitrification inhibitors can reduce N_2O emissions. They can also reduce nitrate leaching in high rainfall circumstances (e.g. if fertilisation occurs in the autumn), though this is not an important effect in the UK.

The smart inventory has the mechanism established to consider this mitigation measure, though currently the evidence on emission effects and on uptake is not fully established. UK experiments have provided evidence regarding the scale of the effect (Cardenas *et al.* 2019, Misselbrook *et al.* 2014), and the emission factor is intended to be derived from a synthesis of experiments. Anecdotal evidence on the uptake suggests that the extent of its use is very low (up to 5-10%). In the BSFP survey that was conducted in 2018, questions were added to assess the types and quantities of inhibitors used. This data has yet to be published. Nitrification inhibitors tend to be conflated with urease inhibitors and slow release fertilisers, thus reducing the reliability of uptake information.

Natural nitrification inhibitors work in the same manner as chemical nitrification inhibitors, but there is scarce evidence so far on their effects

Plant growth promoters

Plant growth promoters can increase the nutrient utilisation of crops, increasing their growth while using the same amount of inputs, including N. In this sense they increase the efficiency of crop production, potentially not reducing GHG emissions on an area basis, but increasing yield and reducing the emission intensity of production. Plant growth promoters are already used (Berry *et al.* 2013), though information on the extent of their use is limited.

The use of plant growth promoters is not included in the smart inventory explicitly. If crop production data is combined with information on N use (available in the inventory by crop and fertiliser type) then efficiency of N use can be estimated; this value will implicitly include the growth promoters' effect on

[3] https://countrysidesurvey.org.uk/

crop production efficiency. However, the potential effects on reducing N losses (due to increased N use efficiency) are not estimated as there is a lack of experimental evidence.

Removing stock from wet ground

Out-wintering beef cattle can cause soil compaction and hotspots of N_2O emissions. One potential solution to these problems is to move stock from wet ground during periods when soil water content exceeds a threshold value. This can be achieved either by temporarily moving cattle to an indoor housing facility (Van der Weerden *et al.* 2017), or by relocating animals for short periods of time to specially designated stand-off pads (Buss *et al.* 2011), which are constructed areas of the field with a surface substrate placed above the soil (Smith *et al.* 2010). The N_2O emissions from grazing are reduced as a consequence of a decrease in the soil water content. Furthermore, the N_2O and CH_4 emissions from manure management change as there is less manure deposited at grazing and more directed to collected (and stored) manure. This measure also has the co-benefit of reducing losses of nutrients to water. It is thought that the current level of stand-off pads in Scotland is very low (Robert Logan *pers. comm.*).

There is no specific representation of this measure in the smart inventory, and for this to happen a full systems analysis would be required taking account of changes in manure management and in field nutrient transformations (reduced prevalence of N_2O hotspots).

High starch diet for ruminants

The composition of ruminant's diet has an effect on the CH_4 emissions from enteric fermentation. In particular, increasing the starch content (e.g. more whole crop silage or grains) reduces enteric CH_4 emissions, mostly through increasing the digestibility of the diet (i.e. lower dry matter intake can provide the same amount of energy); though emissions from land use can increase due to the change from grass to arable crop production.

The smart inventory uses a Tier 3 approach to calculate enteric CH_4 emissions from cattle and sheep. The approach is slightly different from the IPCC approach (IPCC 2006) as it is based on the metabolisable energy content of the diet rather than the gross energy content, and it relates the enteric CH_4 emissions to the dry matter intake rather than the gross energy intake (Brown *et al.* 2018). Based on the growth and yield of the animals, using UK specific equations, the metabolisable energy requirements are estimated. At the same time the diet composition is derived from the John Nix Farm Management Pocketbook[4] for dairy animals, and from the Farm Business Survey for beef cattle. Using the energy content of the diet, the dry matter intake is calculated. The feed type categories are relatively crude, particularly as the concentrates are represented in a single category (other categories include: grazed grass, grazed grass and clover, grass silage, grass and clover silage, maize silage, whole crop silage) (Tom Misselbrook, *pers. comm.*).

The effect of changing starch content on CH_4 emissions from cattle and sheep is captured by the inventory via a change in the diet's digestibility. Additionally, the effects on N excretion (a reduction) are also estimated in the inventory, eventually impacting on N_2O emissions from manure.

Considerable improvement could be achieved in the accuracy of the inventory if statistical data on cattle and sheep feed composition would be available. Furthermore, as the current diet descriptions are based on sources describing English practices, Scottish activity data could also improve the estimates.

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[4] https://www.thepocketbook.co.uk/

High sugar grasses

High sugar grasses have the potential to increase the efficiency of the use of N released from the digested forage (Parsons *et al.* 2011), and thus they have the potential to reduce the proportion of ingested N lost in the form of urine (Parsons *et al.* 2011). This results in a reduction in N lost through leaching and N_2O emissions (Foskolos and Moorby 2017; Parsons *et al.* 2004). The effectiveness of high sugar grasses is dependent on the water soluble carbohydrate : crude protein ratio (Parsons *et al.* 2011). There is also evidence to suggest that they can increase milk production and animal growth rates (Parsons *et al.*, 2011), and evidence suggests they do not reduce enteric CH_4 emissions (Parsons *et al*. 2011, Staerfl *et al.* 2012; Ellis *et al.* 2012). Currently, 62% of livestock holdings with temporary grasslands have sown high sugar grasses (Defra 2018), however, only 30% have sown them on more than 60% of the swards.

High sugar grasses are not included in the smart inventory, as there is insufficient evidence that the water soluble carbohydrate : crude protein ratio is high enough to reduce N leaching losses and N_2O emissions, although it may be effective on low N input systems. Therefore, more evidence on the effectiveness of this measure is required at a national / international scale.

Better livestock health planning

An improvement in the health status of livestock enhances efficiency of the individual animals and the herd, increasing the productivity of the animals and the fertility of the herd. The productivity is expected to increase more than the GHG emissions, thus improving emission intensity.

Currently the health status of the animals is not explicitly included in the smart inventory, however, part of the effects of a change in the health status at the national level would be captured via activity data, like the composition of the herd/flock (e.g. improved fertility increasing the proportion of productive animal categories), slaughter age and liveweight for beef, and dairy milk production. The representation of health effects on feed consumption is not captured in the inventory; feed requirement calculation is based on the average animal performance using energy requirement equations derived from experiments on animals which were healthy.

Measuring the health status and estimating its effect on emissions would be a resource intensive task. At the same time, the feed use and productivity of the herd gives a good indication on GHG emissions and emission intensity, and implicitly includes health status. Therefore, incorporating the health status in the inventory might not improve the GHG estimates significantly. On the other hand, the use of feed statistics to derive actual ration composition and amount instead of industry recommendations would improve the estimation of indirect emission intensity effects.

Breeding ruminant livestock for lower emission intensity

Improvements in animal genetics at a herd level (combining breeding for efficiency traits with breeding for fitness traits) can increase the efficiency of production resulting in a combination of lower feed intake, higher yield and fewer non-productive animals in the herd. This in turn leads to lower CH_4 emissions per unit of livestock produce.

Regarding the effects on emissions, resource use and production, this measure is similar to the 'better livestock health planning' measure. The additional aspect is that the smart inventory identifies different breed categories for cattle and sheep, and thus changes in the proportion of breeds is represented explicitly, though not the changes in the average genetics of the breed.

Ruminant genetic selection for reduced methanogenesis

Individual ruminant animals show a variation in enteric CH_4 emissions (independent of their diet and other external factors). This variance allows selective breeding of animals with lower CH_4 emissions, eventually reducing the CH_4 emissions from the herd.

Currently the smart inventory calculates the CH_4 emission from the rumen based on an empirical model derived from experiments with animals representing the average herd, thus not considering potential changes in the average CH_4 producing capacity of the herd. If animal breeding moves into the direction of reduced methanogenesis, then, to capture that effect, the enteric CH_4 emission calculations will need to be updated with information reflecting the changes.

Covering slurry stores

Covering slurry tanks reduces gaseous losses of ammonia with some reduction of CH_4 emissions. Ammonia loss is a physiochemical process controlled by the ability of ammonia in the slurry to diffuse to the atmosphere (Webb et al. 2013). This method therefore works by restricting the diffusion process by creating a physical barrier to diffusion. The presence of a slurry cover increases the ammonium concentration of the slurry and hence its nutrient value (and potentially subsequent ammonia and N_2O losses).

N_2O and CH_4 emissions are related to the N and volatile solids excreted by the animals, respectively. For cattle and sheep these excretion rates are modelled with a Tier 3 approach, while for excretion values of other livestock and for other parameters the IPCC default Tier 2 method is used (with the exception of CH_4 emissions from slurry covered with natural crust). The N excreted and the gaseous emissions from it are followed through an N-flow approach, which allows for the consideration of effects manure storage technologies on emissions from manure spreading (Brown *et al.* 2018).

Three options are built into the smart inventory to represent the effects of covering slurry stores: rigid store cover, floating store cover, natural crust. Activity data on manure management practices represent the DAs, as derived from available data, which includes the recurring survey on English farm practices (Defra 2018), but only ad-hoc information for Scotland. If the uptake of this measure is expected to change in Scotland, then representing that in the inventory would require updated information on uptake.

Anaerobic digestion of livestock excreta

The treatment of livestock slurry in digestion tank to produce CH_4 for energy involves an anaerobic microbial respiration process which results in an incomplete oxidation of the organic substrate (Pucker *et al.* 2013). The products include both CH_4 and a more stable organic digestate that can be used for application to soil, similarly to undigested excreta. The effects on emissions are three-fold: CH_4, N_2O (and ammonia) emissions from the slurry storage decrease, while N_2O (and ammonia) emissions from spreading the digestate on land might increase or decrease (Insam *et al.* 2015, Möller 2015), and the energy produced can replace energy generated from fossil fuels, therefore reducing CO_2 emissions.

The smart inventory considers the anaerobic digestion of manures regarding the ammonia emission estimates. Though the mechanism is built in the inventory, the GHG emission effect is not calculated at the moment, country-specific emission parameters are not fully established yet. It is an improvement planned for the next inventory submission.

Methane capture and combustion

This measure refers to the capture and combustion of CH_4 from slurry without utilising the heat produced, with a simpler technological solution than anaerobic digestion (the measure is sometimes conflated with anaerobic digestion or the chemical capture of CH_4 in barns). The mechanism of the measure is that CH_4 is converted to CO_2 by combustion, thus reducing its global warming effect. CH_4 can either be flared directly from a slurry store or captured by a chemical substrate and subsequently released and burned.

The smart inventory does not represent the measure via emission parameters and does not have activity data that describes its prevalence.

Summary

The mitigation measures (i.e. activities and technologies which reduce emissions) assessed in this report were found to be represented in the agricultural inventory to a varying degree. While the smart inventory already considers some activities and is planning to include others in the next submission, other activities are only partially, indirectly or not represented at all. Reasons for this include the lack of robust evidence on the effect, the complexity of representation and the lack of detailed activity data. The extent to which the Scottish circumstances and activity levels are considered in the inventory varies too, spanning from data which are annually updated (e.g. N fertiliser use data) to data where UK average values are used, or values are derived from English statistics.

Regarding potential changes in the inventory representation, the measures can be broadly categorised into four groups:

(a) Measures already implemented in the inventory. Collection of Scottish activity data can improve the representation of most of these measures, and if the uptake of them is expected to change then recurring data collection is preferable. Measures belonging to this category are: ‘biological nitrogen fixation in rotations’, ‘biological nitrogen fixation in grassland’, ‘high starch diet for ruminants’ and ‘covering slurry stores’.

(b) Measures which are planned to be implemented in the inventory soon are ‘nitrification inhibitors’ and ‘anaerobic digestion of livestock excreta’. Going forward, Scotland specific activity data could improve accuracy of these measures too.

(c) Measures where the effects can be mostly captured with overall efficiency (and emission intensity) metrics. For these measures most of the data are already available in the inventory and in production statistics, at the DA level. ‘Plant growth promoters’, ‘better livestock health planning’ and ‘livestock breeding for lower emission intensity’ belong to this category. ‘Avoiding N excess’ can be also a measure where current level of representation is sufficient for following broad level trends. Still, improvement in some activity data (particularly ruminant feed) could improve the estimates.

(d) The lack of readily available robust evidence on GHG emission effects prevents the inclusion of some measures in the inventory, like ‘removing stock from wet ground’, ‘higher sugar content grasses’, ‘ruminant genetic selection for reduced methanogenesis’ and ‘methane capture and combustion’.

The following activity data categories can be considered for enhanced data collection at the first place: N fertilisation of minor crops and novel legumes, area and fertilisation information on intercropping, ruminant diets, manure management and storage information.

The measures presented here form a limited set of potential mitigation methods in Scottish agriculture – assessment of further measures might be desirable to reveal additional opportunities. The inventory development is an ongoing process, and a close dialogue with the team preparing the inventory is suggested in order to maximise the effectiveness of data collection and provision effort.

Appendix

Table 2 Detailed findings of the study: mechanism and level of representation in the inventory

Measure	Description of the measure	Mechanism briefly	Level of representation
Avoiding N excess	Eliminating the over-application of nitrogen fertilisers without negative effects on the yield, by a combination of actions including nitrogen management planning and decreasing the error of margin in the applied amount of nitrogen.	Lower N input, potentially a non-linear response to reducing N	Indirectly through fertiliser use
Biological N fixation in rotations	Biological nitrogen fixation provides an input of nitrogen from the atmosphere as a result of the activity of microorganisms that form relationship with legumes (e.g. peas and beans). Part of the fixed nitrogen is also carried over from one phase of a rotation to the next and result in lower N input requirements for the subsequent crop.	Lower N input, carry-over effect (lower N on subsequent crop), less fuel emissions from N spreading	Explicitly through legumes area and fertilisation rate; Carry-over effect represented indirectly via average N rates on other crops; Intercropping with legumes is not represented directly, though N effects shall be included in the average N rates
Biological N fixation in grassland	Biological nitrogen fixation provides an input of nitrogen from the atmosphere as a result of the activity of microorganisms that form relationship with legumes. In grass mixtures legumes (e.g. clover) reduce the requirement for synthetic N fertilisers and reduce nitrous oxide emissions.	Lower N input, leaching, increases livestock's N excretion due to higher N content	Explicitly regarding grass-clover area, specific FracLEach; N fertilisation implicitly derived; effect on N excretion from sheep included explicitly
Nitrification inhibitors and natural nitrification inhibitors	Manufactured products (e.g. DCD) that slow down the microbial transformation known as nitrification in soils, thus reducing nitrous oxide emissions.	Reduces EF_1	Explicitly, but EF_1 and activity data yet to be established

Measure	Description of the measure	Mechanism briefly	Level of representation
Plant growth promoters	A range of microbial and non-microbial soil additives that are used to increase nitrogen uptake and growth of plants, potentially reducing nitrous oxide losses from the soil, but also increasing nitrogen in crop residue.	Increases N uptake and growth (yield) by plants, potentially reducing N losses from the soil, but also increasing N in crop residue	Indirectly through fertiliser use (with additional data on yield); Crop residue N indirectly through yield statistics; N losses as N_2O, NH_3, leached N: no parameters set for growth promoters
Removing stock from wet ground	Out-wintering beef cattle can cause soil compaction and hotspots of GHG emissions. Moving livestock from wet ground during periods when soil water content exceed a threshold value can solve this problem.	Reduces soil compaction and therefore high N_2O emissions (EF_1), the emissions from excretion changes for the stand off period too	Not included, effects would not be captured indirectly either (potentially manure management effect can be)
High starch diet for ruminants	Increasing the digestible energy content of the diet by increasing the amount of starchy concentrates in the ration, while keeping the total crude protein content of the diet constant. Reduces the rate of enteric methane excretion.	Reduces enteric CH_4 emissions (via increasing digestibility) and N excretion	Included, though activity data (ration composition) are derived from industry recommendations rather than from current statistics
Higher sugar content grasses	High sugar content grasses have been bred to express with elevated concentrations of water-soluble carbohydrate. They have the potential to increase the efficiency of the use of nitrogen released from the digested forage, and consequently reduce the proportion of ingested nitrogen lost to the environment.	Reduces N excreted, can increase milk yields and animal growth rates	Not included, potential N excretion and enteric CH_4 effect are not captured; indirectly effects on milk yield and growth rate are included
Better livestock health planning	Improving animal health could in principle lead to significant reductions in emissions intensity by, for example, improving the feed conversion ratio of individual animals and reducing the herd breeding overhead (through improved fertility and reduced mortality).	Increases productivity of the herd (reduces emission intensity), but unlikely to lead to reduced absolute emissions	Not included explicitly (representing the specific health improvements would be very complex both regarding emission parameters and activity data); indirect yield and herd structure effects are captured

Measure	Description of the measure	Mechanism briefly	Level of representation
Livestock breeding for lower emission intensity	Improvements in animal genetics at a herd level can increase the efficiency of production resulting in lower feed intake and/or higher yield. Lower emission intensity results from combining breeding for efficiency traits with breeding for fitness traits.	Animal and herd level efficiency improvements resulting in lower feed intake and/or higher yield	Indirectly through emission estimates and production data
Ruminant genetic selection for reduced methanogenesis	Inclusion of the methane production in the breeding goal would result in selection for ruminant animals which produce less CH4 without a compromise in their yield or feeding requirements.	Reduces enteric CH_4 with no change in the diet and no decrease in the yield	Not included, effects would not be captured indirectly either (if no production effects)
Covering slurry stores	Covering the slurry tanks with a retrofitted cover to reduce - mainly - ammonia emissions, though CH_4 emissions can be reduced too. A reduction in ammonia losses leads to reduced indirect N_2O emissions.	Reduces gaseous losses of ammonia with some reduction of CH_4, acting as a physical barrier for diffusion into the atmosphere	Represented directly via three options (rigid store cover, floating store cover, natural crust), with parameters and activity data
Anaerobic digestion of livestock excreta	Treating slurry in anaerobic digesters to produce electricity and/or heat (and using the digestate as a fertiliser). Some plant-based biomass will be added as feedstock.	Reduces CH_4 and N_2O emissions from manure storage, reduce/increase N_2O emissions from land application of digestate, replaces energy	The mechanism is built in, it is intended to be included in the next submission of the GHG inventory
CH_4 capture and combustion	Covering the slurry pit with an impermeable cover and collecting and flaring the methane generated during the storage.	Converts CH_4 to CO_2 reducing the global warming potential	Not included, effects would not be captured indirectly either

Table 3 Detailed findings of the study: data used in the inventory

Measure	Parameters representing effect	Activity data used	Scottish data used in the inventory?
Avoiding N excess	None (non-linear response of N_2O emissions on N application is not included in EF_1)	Fertiliser N use (synthetic): from the BSFP; It would be difficult to estimate optimal N use (easiest could be to assume that the fertiliser recommendations are the optimal quantity); The BSFP is not granular enough to pick up field level N application rates (FAS and JAC could be combined to see which crops are grown on which plots and with how much N)	N fertiliser use is already by DA in BSFP, though the sample size is small
Biological N fixation in rotations	Not needed	Legume crop areas, fertiliser N input on legumes; Fertiliser N input on other crops; Intercropping with legumes: not recorded in JAC or BSFP	Crop areas: yes; Legumes N rates: BSFP data based on a sample of 1,160 farmers across the UK (in 2017), DA specific, but small sample from Scotland particularly for novel legumes; N rates of other crops (carry-over effect): DA specific N rates in the BSFP
Biological N fixation in grassland	FracLeach, grass-clover N content	Grass-clover area derived from Countryside Survey; N fertilisation rate derived from BSFP	Area and N rate: Countryside Survey and BSFP sampled Scotland
Nitrification inhibitors and natural nitrification inhibitors	None	None	None
Plant growth promoters	None	Indirectly through yield statistics and fertiliser use (BSFP)	N fertiliser use: DA specific from BSFP; Yield: DA specific from JAC

Measure	Parameters representing effect	Activity data used	Scottish data used in the inventory?
Removing stock from wet ground	None	Might be represented in the manure management system activity data if the effluent is collected and reported as stored manure (but uptake is likely to be too low for it to be actually recorded in any sample)	None
High starch diet for ruminants	Digestible energy and crude protein content of feed components; Concentrates are represented as a single category	Feed composition: dairy: Nix Pocketbook, beef: Farm Business Survey	None
Higher sugar content grasses	None	None	Milk yield (by production intensity - breed proxy): DA specific (annual values derived from publications by the Centre for Dairy Information and normalised to agree with DA milk production statistics); Beef slaughter weight: DA specific
Better livestock health planning	None	Average milk yield, slaughter age and weight and herd structure: annual statistics; feed consumption: based on the average animal performance using energy requirement equations derived from experiments on healthy animals	Milk yield (by production intensity - breed proxy): DA specific (annual values derived from publications by the Centre for Dairy Information and normalised to agree with DA milk production statistics); Beef slaughter weight: DA specific
Livestock breeding for lower emission intensity	None	Average milk yield, slaughter age and weight and herd structure: annual statistics; feed consumption: based on the average animal performance using energy requirement equations derived from experiments on animals which were probably in the healthy range? (So we might be slightly underestimating feed consumption?)	Milk yield (by production intensity - breed proxy): DA specific (annual values derived from publications by the Centre for Dairy Information and normalised to agree with DA milk production statistics); Beef slaughter weight: DA specific

Measure	Parameters representing effect	Activity data used	Scottish data used in the inventory?
Ruminant genetic selection for reduced methanogenesis	None	None	None
Covering slurry stores	N volatilisation factor, CH_4 conversion factor	Yes, based on the Farm Practices Survey (Defra) and other sources	Slurry cover uptake: yes, but data sources for annual update are not available
Anaerobic digestion of livestock excreta	Manure management system emission parameters; land spreading emission parameters	Yes, sourced from Centre of Ecology and Hydrology	Probably none
CH4 capture and combustion	None	None	None

Table 4 Detailed findings of the study: interactions and suggestions

Measure	Does any off-farm emission effects get recognised in the inventories of other sectors?	Interactions with other measures	Summary suggestions for inventory changes required to represent mitigation more accurately
Avoiding N excess	No fertiliser industry in the UK, so fertiliser off-farm effects are not captured in the UK	With all measures targeting N fertilisation	Representation of the measure would require establishing field-level N optima and comparing it with field-level N application data; Introducing full non-linear EF_1 could improve estimates; Trends of N use (and N_2O emissions) by crop and fertiliser type are estimated; that together with crop production data can inform on efficiency of N use
Biological N fixation in rotations	No fertiliser industry in the UK, so fertiliser off-farm effects are not captured in the UK; Transport sector might pick up fuel use reduction from less N spreading (depending on how granular the agricultural machine use data are)	With all measures targeting N fertilisation	Some improvements could potentially be achieved by using more granular N application data (particularly regarding intercropping and carry-over effect)
Biological N fixation in grassland	No fertiliser industry in the UK, so fertiliser off-farm effects are not captured in the UK	With all measures targeting N fertilisation	Bigger sample of Scotland specific clover-grass area and fertilisation data at the farm scale could improve estimates for Scotland
Nitrification inhibitors and natural nitrification inhibitors	Emissions related to the production of nitrification inhibitors might be implicitly included in the industry inventory if they are produced in the UK	With all measures targeting N fertilisation, including fertiliser type, urease inhibitors	Scotland specific data on the use of nitrification inhibitors if uptake starts increasing could help accuracy
Plant growth promoters	Emissions related to the production of growth promoters might be implicitly included in the industry inventory if they are produced in the UK	With all measures targeting N fertilisation and crop N use efficiency	N use efficiency in Scotland can be already established from inventory data and yield data (indirectly includes effect); evidence of other effects (e.g. on N leaching) needs to be established

Measure	Does any off-farm emission effects get recognised in the inventories of other sectors?	Interactions with other measures	Summary suggestions for inventory changes required to represent mitigation more accurately
Removing stock from wet ground	Emissions related to the production of stand-off pads might be implicitly included in the industry inventory	Drainage	Collation of evidence (as of how soils wetness affects emissions) would be needed as well as baseline data on the number of wet days and collection of activity information
High starch diet for ruminants	Effects on agricultural emissions in other countries (due to changes in imported feedstuff) are included in those GHG inventories	Other feeding measures	Statistical (including Scottish) data collection on rations could improve the representation of the measure
Higher sugar content grasses	Not applicable	Other feeding measures	Representation of the measure would require establishing emission parameters and collection of activity data (sales data available, but not the extent of high sugar grasses in the fields or their nutritional composition, which is important for the mitigation effect and depend on the N fertilisation rate of the grassland)
Better livestock health planning	Not applicable	Livestock feeding and breeding measures	Indirect emission intensity effect can be derived from the inventory, though that could be improved with statistical data on feeding
Livestock breeding for lower emission intensity	Not applicable	Livestock breeding measures	Indirect emission intensity effect can be derived from the inventory, though that could be improved with statistical data on feeding
Ruminant genetic selection for reduced methanogenesis	Not applicable	Livestock breeding measures	Representation of the measure would require the update of enteric methane emission parameter

Measure	Does any off-farm emission effects get recognised in the inventories of other sectors?	Interactions with other measures	Summary suggestions for inventory changes required to represent mitigation more accurately
Covering slurry stores	Emissions related to the production slurry of covers might be implicitly included in the industry inventory	All manure management measures, also some livestock feeding measures and manure spreading measures	Collection of Scotland specific activity data
Anaerobic digestion of livestock excreta	Indirectly the reduced energy use is captured via reduced emissions from energy used; Emissions related to the production of equipment might be implicitly included in the industry inventory	All manure management measures, also some livestock feeding measures and manure spreading measures	Collection of Scotland specific activity data
CH_4 capture and combustion	Emissions related to the production of equipment might be implicitly included in the industry inventory	All manure management measures, also some livestock feeding measures and manure spreading measures	Representation of the measure would require establishing emission parameters and collection of activity data

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